The Wide-Field Infrared Explorer (WIRE)

Helene Schember and Perry Hacking

Jet]'repulsion Laboratory
California Institute of Technology
Pasadena, CA 91109

ABSTRACT

More than 30% of current star formation is taking place in galaxies known as starburst galaxies. Do starburst galaxies play a central role in the evolution of all galaxies, and can they lead us to the birth of galaxies and the source of quasars? We have proposed to build the Wide Field Infrared Explorer (WIRE), capable of detecting typical star-burst galaxies at a redshift of 0.5, ultraluminous infrared galaxies beyond a redshift of 2, and luminous protogalaxies beyond a redshift of 5. This instrument will survey about 100 deg^2 of high Galactic latitude sky at 12 and $25\mu m$, in passbands where 20% of the luminosity from local starbursts is radiated. WIRE will measure the $12-25\mu m$ color of the starburst galaxies, which is a powerful statistical luminosity indicator. The distribution of starburst galaxy $12-25\mu m$ colors as a function of flux density will reveal their evolutionary history and perhaps the presence of protogalaxies at high redshifts.

During its four-month mission lifetime, WIRE will gather important data on starburst galaxies and amass a catalog exceeding the size of the IRAS Point Source Catalog. WIRE is specifically designed to detect the maximum number of high-redshift starburst galaxies using an extremely small and simple instrument. The 28cm aperture Cassegrain telescope has no moving parts and a wide 34 x 34 arcminute field of view. It capitalizes on the 128 x 128 Si:As IBC detector arrays now available. The optics and detectors are cooled during the mission using only 3 kg of solid H_2. A three-axis stabilized spacecraft designed and build by the Goddard Space Flight Center Small Explorer Project Team would be used. The WI RE instrument requires only a single stare-type observing mode, fixed solar panel, 35 watts of power, and a low data rate (7 kbits/sec average).

1.0 INTRODUCTION

In response to the NASA Small Explorer (SMEX) program, we have proposed to conduct a 4-month survey at 12 and 25pm to unprecedented flux-levels covering more than 100 deg^2 of sky. This survey, conducted by the Wide Field Infrared Explorer (WIRE), will provide an increase in sensitivity of a factor of 500 over the IRAS Faint Source Catalog. Figure 1 depicts an overview of the WIRE objective, instrument and mission. The WIRE survey will detect primarily galaxies with unusually high star formation rates, or “starburst” galaxies. The resulting catalog of at least 20,000 starburst galaxies will contain their evolutionary history out to redshifts of 0.5-1 and the evolutionary history of extremely luminous galaxies beyond redshifts of 5.

Understanding the formation and evolution of galaxies is one of the most important goals of modern astronomy. Starburst galaxies are an important population because they represent 30% of the energy budget of the local Universe, and therefore an even greater fraction of its current star formation. Models of protogalaxies also predict ultraluminous starbursts at early epochs. It is possible that most stars have formed in starburst galaxies. WIRE will help reveal the role of starbursts in the evolution of all galaxies.

The scientific impact of the WIRE data will be immediate. The number of sources as a function of flux density will indicate the evolutionary rate of starburst galaxies. The infrared color distribution of sources detected as a function of flux density will reveal the nature of the evolution of starburst galaxies. Follow-up observations at other wavelengths will test our assumptions and are likely to lead serendipitously to new discoveries.

Since the WIRE survey reaches so deeply into unexplored territory, it presents an enormous opportunity to the entire astronomical community for scientific investigation and discovery. Examples of additional investigations include exploring the proposed link between quasars and ultraluminous galaxies, searching for brown dwarfs, searching for circumstellar disks around main sequence stars, and exploring the large-scale distribution of galaxies at high redshifts.

BASIC DESCRIPTION

WIRE is a two-color, solid H_2 cooled, imaging telescope operated n low earth orbit for 4 months to study evolution of starburst galaxies

Parameter	Requirement	Baseline
Total Mass	$\leq$ 250 kg	191 kg
Total Power	$\leq$ 300 w	145 w
Instrument Mass	$\leq$ 75 kg	61 kg
Instrument Power	$\leq$ 50 Watts	$\leq$ 35 Watts
Size	Fit Pegasus Shroud	68 cm (dia) x 83 cm Fits in Pegasus

OBJECTIVE OF WIRE

To answer three questions:

I. (1) What fraction of the luminosity of the Universe at . redshift of 0.5 and beyond is due to starburst galaxies?

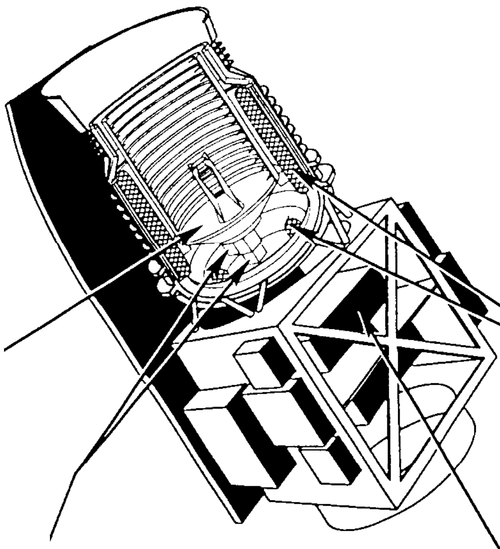
(2) How fast and in what ways are starburst galaxies evolving?

(3) Are luminous protogalaxies common at redshifts less than 3,

KEY SCIENCE REQUIREMENTS – 1

Parameter	Requirement	Baseline
Sensitivity, 25μm:	Confusion-limited*	RMS Confusion Noise=0.06mJy, Instrumental Noise = 0.04 mJy in 11,000 seconds
Sensitivity, 12μm:	$Noise_{Total}(12\mu m) < Noise_{Total}(25\mu m)$	$Noise_{Total} \sim 0.012$ mJy
Sky coverage	25 deg^2	112 deg^2
Sources detected	20,000	90,000
Typical distances	z > 04 (z = redshift)	z $\approx$ 0.5

* Confusion limited implies Instrumental Noise < Confusion Noise



WIRE OPTICS

Parameter	Requirement	Baseline
Spectral Range	Band 1 $\leq$ 15μm, $\lambda/\Delta\lambda$ = 2	Band 1: 9-15 μm
	Band 2 $\geq$ 23μm, $\lambda/\Delta\lambda \leq 5$	Band 2 22-28 μm
Aperture	$\geq$ 25 cm	28 cm
Image Quality	Diffraction limited, Band 2	Diffraction limited, Bands 1 & 2
Field of View	maximize	34 arcmin
Transmission	maximize	68% (Band 1), 60% (Band 2)
Optics Temp	<17.5 Kelvin	13 Kelvin

CRYOSTAT

Parameter	Requirement	Baseline
Type		Dual stage, solid H_2
Mass	< 50 kg	38 kg
Primary tank temp	$\leq$ 8 K	7 K
Secondary tank temp	$\leq$ 17 K	12 K
Primary tank volume		3.8 liters
Secondary tank volume		36 liters

WIRE DETECTORS

Parameter	Requirement	Baseline
format	96 x 96 pixels (75 μm)	128 x 128 pixels (75 μm)
pixel size	Adequately sample PSF	15.8 arcsec 5 pixel/FWHM
dark current	< 500 e^-/sec	150 e^-/sec
quantum efficiency	>0.3	> 0.4
read noise	< 1 80 RMS c/pixel	< 180 RMS e^-/pixel
temperature	<8 Kelvin	72 Kelvin

MISSION DESCRIPTION

Parameter	Requirement	Baseline
Lifetime	3 months	4 months
Orbit Altitude	400 km	400 km"*"
Orbit Inclination	$\geq$65°	sun-synchronous
Exposure Length	maximize	32 sec in Band 1 (12μm) 6-4 sec in Band 2 (25μm)
Downlinks	$\leq$2 per day	2 per day
Total Data		10 Gbytes
Observing Efficiency*	> 50%	73%
Sun Avoidance	minimize	> 80°
Earth Avoidance	minimize	>150"
Moon Avoidance	minimize	> 20°**

*Primary target efficiency is 37%

**For data taking only

***Includes 15% mass margin

SPACECRAFT

Parameter	Requirement	Baseline
Mass	189 kg	130 kg estimated
Power	265 W	110 W estimated
Solar Panels		Fixed, 1.5 m^2
Pointing Accuracy (2σ, radial)	$\approx$ 2 arcmin	30 arcsec
Pointing Stability (2σ, radial)	19 arcsec	12 arcsec
Average Data Rate	$\leq$ 15 kbits/sec	6.7 kbits/sec
Peak Data Rate	$\leq$ 100 kbits/sec	9 2 Kbits/sec
Data Storage	<1 Gbit	0.256 Gbit

Figure 1. Wide-Field Infrared Expiorer (WIRE) overview.

There is great potential for discovery of entirely ncw phenomena at these faint flux levels. The opportunity for such enormous gains in sensitivity over a large part of the sky arc rare for such a small and simple mission.

The WIRE instrument consists of a 28 cm Cassegrain telescope that is cooled by a solid cryogen. It has no moving parts and no reimaging optics. The Si:As detectors, currently available, provide a revolutionary improvement in sensitivity and areal coverage over those available only a few years ago. The cryogen selected is solid hydrogen, which provides the least massive, most thermally robust cryostat to meet our temperature requirements. The cryostat has no cold valves or porous plugs. Liquid helium can be used in the cryostat for ground testing. The spacecraft requirements arc less difficult than those of the SMEX spacecraft previously designed. The 4-month lifetime and straightforward survey strategy further enhance the simplicity of tbc WIRE mission.

The Si:As detectors selected for WIRE make a landmark science investigation possible within the context of a small mission. WIRE will produce a data set of great scientific richness that builds measurements by ESA's In frared Space Observatory (1S0) of the spectral energy distributions of nearby" starburst galaxies and guides the science planning for the Space Infrared Telescope Facility (SIRTF) by identifying targets for further study.

2.0 SCIENCE OBJECTIVES

The objective of the WIRE mission is to answer three questions: (1) What fraction of the luminosity of the Universe at a redshift of 0.5 and beyond is due to starburst galaxies? (2) How fast and in what ways are starburst galaxies evolving? (3) Arc luminous protogalaxies common at redshifts less than 3? This will be accomplished by conducting an ultra-deep survey at 12 and 25pm as faint as 0.21 mJy, (5-σ), at 25pm, with RMS positional accuracies of less than 2.5 arcseconds.

This will be the first significant galaxy survey to probe these redshifts at far-infrared wavelengths"* where extinction effects are small and where most of the bolometric luminosity of starburst galaxies, and possibly of the Universe, can be measured.

3.0 BACKGROUND AND JUSTIFICATION

3.1 Recent Results

Most of the efforts to understand the evolution of galaxies and search for protogalaxies have been at visual, near-infrared, and radio wavelengths. Most of these surveys have looked for changing luminosities, number densities, or colors of sources with lookback time. One message seems to be clear: galaxies with high star-formation rates are an important population and play an increasing role in the energetic of the Universe at earlier epochs,

This picture of star formation in distant galaxies is incomplete because most of the luminosity generated in star-forming regions is absorbed by dust and re-radiated in the far-infrared, where no deep surveys have been conducted. The detection of I RAS F10214+4724 at a redshift of 2.3[2] suggests that this is also true at high redshifts. The far-infrared luminosity of a galaxy can provide a direct indication of its star-formation rate. A deep, far-infrared survey can thus determine the evolution of star-formation with time.

3.2 The IRAS Survey

The lRAS Survey provided our first full view of the far-infrared sky. IRAS's 59 detectors, with passbands centered at 12, 25, 60, and 100pm, sensed mainly thermal emission from dust. IRAS revealed a high Galactic latitude sky filled with luminous galaxies undergoing bursts of star formation. WIRE provides the next step. Typical galaxies from 1 RAS' far-infrared flux-limited sample have luminosities of order $10^{10}L_\odot/h^2$.† These galaxies produce 70% of their luminosity longward of 8pm, while about 20% of them produce more than 90% of their power in the far-in frared[3]. Studies of infrared-luminous galaxies, such as M82, M83, and NGC 253, indicate that the source of their large infrared luminosity is a large population of young, massive stars, which implies a high star-formation rate. The star-formation rate implied by the infrared luminosity could be sustained by the galaxy's observed gas supply for

* It would take almost six weeke of 1S0 observing time to survey one square degree in a single band at 15 μm to the same areal source density as would be found in the WIRE survey.

** Far-infrared refers to 8-1000μm in this paper. About 40% of the far-infrared luminosity from starburst galaxies is radiated from 8-40μm[1].

† h = Hubble's constant/(100 km/s/Mpc). Predicted number counts and redshift distributions are independent of Hubble's constant, $L_\odot$ is the luminosity of the Sun

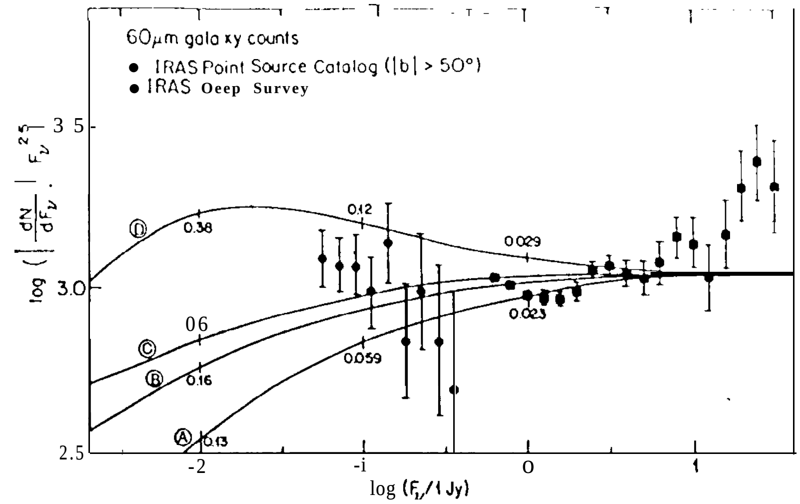


Figure 2, Predicted and observed 60pm differential source counts (number per steradian, per Jansky, times $F_\nu^{2.5}$). Predicted source counts arc shown by solid curves. Tick marks are predicted median redshift of the sources at that flux density. The four evolutionary models shown are A) no evolution, B) and C), strong density evolution ($1+z)^{3,4}$, and D) strong luminosity evolution ($1+z)^{\sim 4}$, equal to that observed for quasars and radio galaxies at 1.4 GHz[1]. Number counts are from the IRAS Point Source Catalog and from the small ecliptic pole survey[6]. This figure depicts the number counts at 60μm because IRAS' higheat areal source density has been achieved at this wavelength. The areal sours density that WIRE will achieve at 25μm would be found beyond the left boundary of the figure.

only a small fraction (typically <0.1) of a Hubble time, hence the term "starburst galaxy" is often used to describe them.

Starburst galaxies comprise 10% of the galaxies in our vicinity, Their luminosity and scarcity compared to optically selected galaxies makes them effective cosmological probes when observed in the infrared because a large volume can be sampled before the telescope confusion limit is reached,

3.3 Evolution of Starburst Galaxies

The total luminosity radiated from galaxies at 8-1000pm, which is dominated by starburst galaxies, amounts to about 30% of the total bolometric luminosity from matter in the local Universe. This implies that more than 30% of the local star formation is occurring in starbursts. If they were more luminous or more abundant in the past, starburst galaxies could represent most of the luminosity of the Universe beyond a redshift of 0.5. Most stars, including the Sun, may have been born during starbursts.

A study of brighter IRAS galaxies[4] has not detected evolution, although the proximity of the brighter galaxies to us makes the prospects of detecting evolution marginal. Studies of the faintest galaxies from the IRAS survey give tantalizing evidence for the evolution of starburst galaxies as shown in Figure 2 [5,6,7,8,9].

Even though starburst galaxies are luminous, the IRAS sample is still relatively close. The mode of the redshift distribution of the deepest survey at the ecliptic pole, which contains fewer than 100 galaxies, is 0.08 [10]. Surveys over small volumes such as this can be seriously affected by the presence of large scale structure. Shallower IRAS samples survey more volume and large scale structure is less of a problem, but the galaxies are nearer and evolution is more difficult to detect.

Luminosity evolution cannot be distinguished from density evolution using the IRAS data.* The WIRE survey will be able to detect evolutionary rates at least an order of magnitude lower than the upper limits, shown in Figure 3.

Number counts in a single, 34 x 34 arcminute field from the WIRE survey will resolve whether evolution is occurring or not. The first day of WIRE science observations will result in 3 completed fields. Each field will contain

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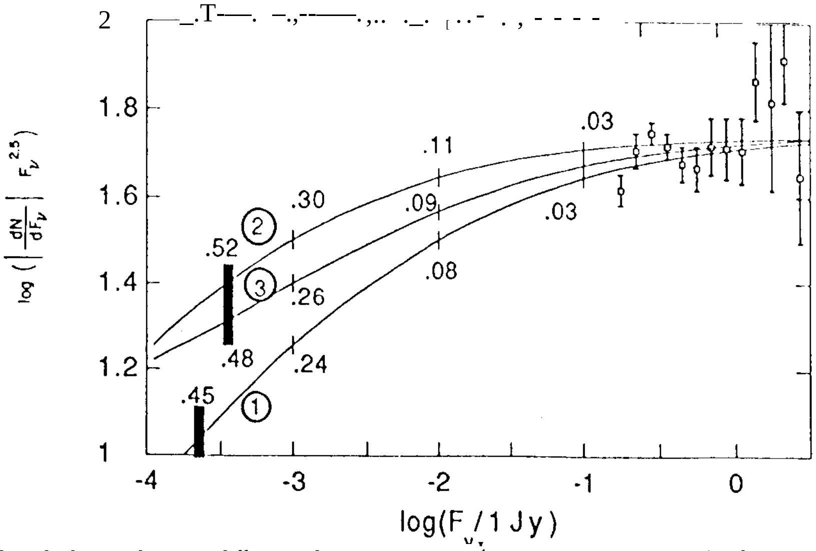
* Luminosity and density evolution correspond to pure translations of the luminosity function along the luminosity and number density axes, respectively. i.e., $\rho(L, z) = g(z)\rho(\frac{L}{f(z)}, z = 0)$, where $\rho(L, z)$ is the number of sources per eomoving volume element of luminosity L at a redshift of z; and f(z) and g(z) correspond to pure luminosity and density evolution, respectively.



Figuro 3. Predicted and observed 25pm differential source counts (same units as Figure 2). The curves represent: 1) no evolution, 2) moderate luminosity $(1+z)^{2.5}$, and 3) density evolution $(1+z)$. Models 2 and 3 both have a WIRE RMS confusion noise of 0.060 mJy, which is our baseline. Model 1 has a WIRE RMS confusion noise of 0.034 mJy. The WIRE 5-u flux limits (dominated by the confusion noise) are represented by bold bars. Tick marks indicate median redshift at that flux density. Number counts are from the IRAS Faint Source survey. The deviation of models 2 and 3 from the no evolution case shows that the large sample of galaxies from the WIRE survey can detect evolutionary rates as slow as $(1+z)^{0.3}$.

over 200 starburst galaxies. The infrared colors and number counts measured by WIRE will determine the rate and kind of evolution that is occurring out to redshifts of 0.$1.

3.4 Ultraluminous and Primeval Galaxies

The IRAS survey discovered the ultraluminous infrared galaxies ($L_{IR} > 10^{12} L_\odot/h^2$) which match or exceed quasar luminositics[3,12] and dusty quasars which appear to link the two[3]. There is strong evidence that ultraluminous starbursts are triggered by tidal effects in interacting or merging galaxies[3,12]. The fraction of galaxies that appear to be members of interacting or merging pairs rises from 10% at a far-infrared luminosity of $10^{10}L_\odot$ to essentially 100% beyond a luminosity of 10121,.. It has been postulated that these ultraluminous galaxies represent a separate population from the more typical starburst galaxies[14]. The WIRE survey will be able to determine whether this most luminous end of the luminosity function is in fact evolving separately from the rest of the starburst population.

3.5 WIRE

A survey with passbands centered at 12 and 25pm is ideal for studying the evolution of starburst galaxies. First, the passbands include a significant fraction (20% for typical starburst galaxies) of the far-infrared luminosity produced by the starburst. Second, the 12–25pm color correlates with the total far-infrared luminosity[15,1]. Third, extinction effects are small. Fourth, the confusion limit lies at higher redshifts than at longer wavelengths for a fixed telescope aperture.

Recent advances in infrared detectors have now made such a survey possible. A new generation of Si:As IBC arrays now exist, that have vastly better noise characteristics and much larger formats than did the detectors available only a few years ago. These detectors are the heart of the WIRE experiment. A small, cooled telescope placed in front of these detectors will provide a revolutionary gain in sensitivity and field of view. This is why a telescope with less than one fourth of the collecting area of IRAS can produce a large area catalog of galaxies 500 times fainter than those found in the IRAS Faint Source Catalog.

4.0 INVESTIGATION APPROACH

Approximately 95% of WIRE detections will be starburst galaxies at 12 and 25pm, The survey will also detect stars, quasars, elliptical and early-type spiral galaxies, circumstellar and interstellar dust, and perhaps even some brown dwarfs.

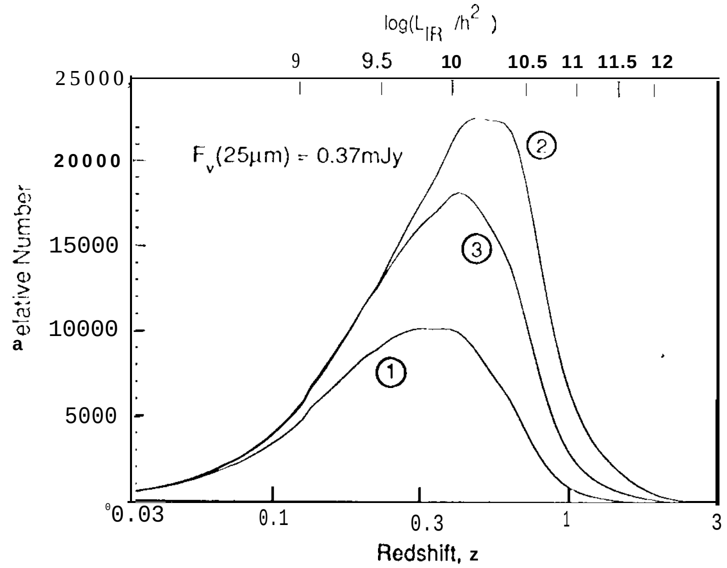


Figure 4. Predicted redshift distributions for the three models in Figure 2 at 0.37 mJy, our baseline confusion limit. Luminosity evolution reveals itself with a high-redshift tail in the distribution (at a fixed confusion limit). Stronger evolutionary models will give about the same mode of the redshift distribution at their brighter confusion limits, but will have more prominent high-redshift tails. The upper scale shows the mean luminosity as a function of redshift.

The WIRE survey will be confusion-limited at 25 μm. This means that the dominant source of flux uncertainty (noise) will be due to the the differing numbers of extremely faint, individually indistinguishable background sources present in adjacent resolution elements (or telescope "beams"). The RMS amplitude of this "structure" on the sky is fixed for a given telescope point spread function. Once it becomes the primary contributor to the flux uncertainty, no amount of integration time can reduce it further. All calculations that we give assume detections that are at least 5 times the total noise, which includes the RMS confusion noise and instrumental noise.

The confusion limit for WIRE lies at about 850 sources/deg^2 at 25 μm.† The flux limit where this areal density is reached depends on the evolutionary rate of the sources. The upper limit of the evolutionary rates mentioned previousl y correspond to a 25pm RMS confusion noise of about 0.12 mJ y. No evolution would result in a confusion noise of 0.034 mJ y. The 4-month mission life and a 73% observing efficiency* for a typical orbit permits a 1000 deg^2 survey for the first case, and a 33 deg^2 survey for no evolution. Our ba.dine assumes a confusion noise of 0.060 mJy, an instrumental noise of 0.042 mJy, and a 5-σ flux limit of 0.37 mJy and a sky coverage of 110 deg^2. These coverage areas contain a great deal of margin. Even a 25 deg^2 survey will result in over 20,000 galaxies detected down to the WI RE confusion limit, including hundreds of ultraluminous galaxies.

WI RE's 12μm sensitivity is about six times fainter than the 25μm limit for the same exposure time WIRE will not be confusion limited at 12pm. Since the role of the 12pm band is to provide a color measurement for the 25pm sources, we can usc detections as faint as 3σ at 12pm at the position of a 25pm 5σ detection for a color measurement (with due consideration to selection effects). Over 95% of the 25μm detections will have a 12pm detection at >3σ. The number of sources, the 12–25pm color, and its correlation with far-IR luminosity will provide the discriminator among the different evolutionary models as shown in Figures 4 and 5,

The WIRE survey will consist of repeated observations of about 400 fields at high Galactic latitude (|b|>40°) to accumulate sufficient exposure time to reach the confusion limit. The total exposure time required for the baseline case is 11,000 seconds and about 3 fields per day can be completed, Each exposure, lasting 32–64 seconds, will be natural background limited. Fields will be selected away from the ecliptic plane (to minimize the background and

† For a static, Euclidean distribution of sources, the confusion limit is at about 60 telescope "beams" per source. Since the number counts are dropping rapidly at these faint flux levels (see Figure 3) the WIRE confusion limit occurs at slightly over 30 "beans" per source.

• Conservative assumptions about data loss, calibration times, etc give an overall science target efficiency of 37%, as described below, These assumptions result in the survey coverage cited above.

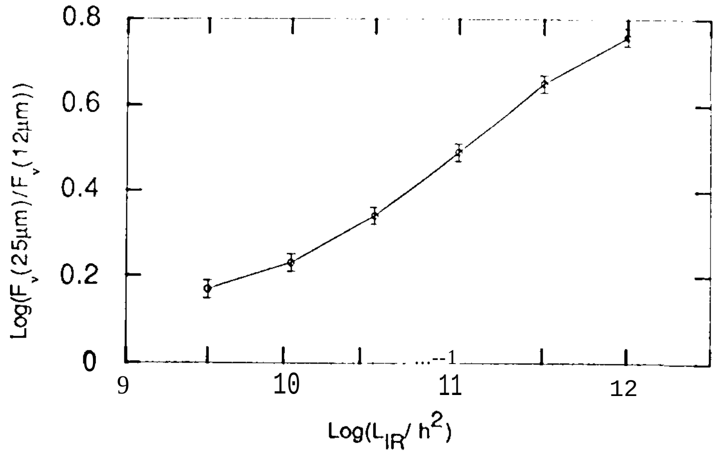


Figure 5. Mean 12–25pm color vs. far-infrared luminosity. Each data point shows the mean color for galaxies of that luminosity[1]. The error bars represent errors in the mean for 100 galaxies in that bin. 'This error includes the effects due to the silicate absorption/emission feature in the 12pm passband. The Figure shows that 12-25μm color is a good statistical luminosity indicator.

contamination from comet trails, asteroids, etc), towards holes in the infrared cirrus seen in the lRAS survey, and preferably in regions covered by optical redshift surveys.

Our pointing stability requirement is 19 arcseconds (2σ). This means that pointing jitter and diffraction will contribute equally to the point-spread function (and thus the confusion-limited flux limit). The SMEX spacecraft capabilities are like] y to exceed this performance by a factor of 2–3. We use a goal of 12 arcseconds for sensitivity and confusion-noise estimates.

Each individual observation, or exposure, needs to have a pointing accuracy of order l-arcminute relative to the others to ensure efficient use of the field of view. This is well within the SMEX spacecraft capabilities. The data will be flat-fielded, registered, and coadded on the ground. The images will be registered using sources present in the field of view at both 12 and 25 μm. Sources will be extracted from the images using standard software and a catalog will be produced for use by the entire community.

WIRE requires only 30 watts of power, It has only one observing mode, It requires 32 Mbytes of onboard data storage and has an average data rate of 7 kbits/sec.

5.0 THE WIRE INSTRUMENT

WIRE represents an enormous advancement over previous infrared missions yet is also easy to build and operate. The WIRE instrument design maintains simplicity throughout. Although far smaller and less elaborate than IRAS and COBE, WIRE is a typical space-based infrared telescope. The design is a direct descoping of the previously implemented design for the third-generation Spatial Imaging Infrared Telescope (SPIRIT 11 I)[16]. This instrument was built by the Utah State University Space Dynamics Laboratory (S1)1.) for the Midcourse Space Experiment (MSX) program.

The WIRE instrument consists of a 28 cm baffled Cassegrain telescope which illuminates two array detectors, as shown in Figure 6. A dichroic beamsplitter separates the incident energy into two broad wavelength bands centered around 12 and 25 pm. These beams illuminate two identical arsenic-doped silicon (Si:As) IBC focal plane arrays. The entire optical train is comprised of the primary mirror, secondary mirror, dichroic, stationary filter and the two 128 x 128 Si:As detectors, The total optical system is maintained at the desired temperature by a passive, solid H_2 cryostat of proven design, as shown in Figure 7, The cryostat cools the detectors to 7.2 K and the optics and baffles to 13 K. The cryostat is sized to provide a 4 month lifetime. An angled, two-stage sunshade prevents direct Earth and Sun impingement inside the telescope aperture. There are no cold mechanisms or moving parts; in particular, there are no filter wheels, flip mirrors, focus mechanisms, shutters or cryogenic valves on this system.

The WIRE instrument shown here would be launched using the Pegasus launch vehicle. The science objectives can be achieved using either the standard or enhanced versions of this vehicle. The solid H_2 cryostat is a reliable system based on a previously executed and tested design. Liquid helium will be used in the cryostat for all ground

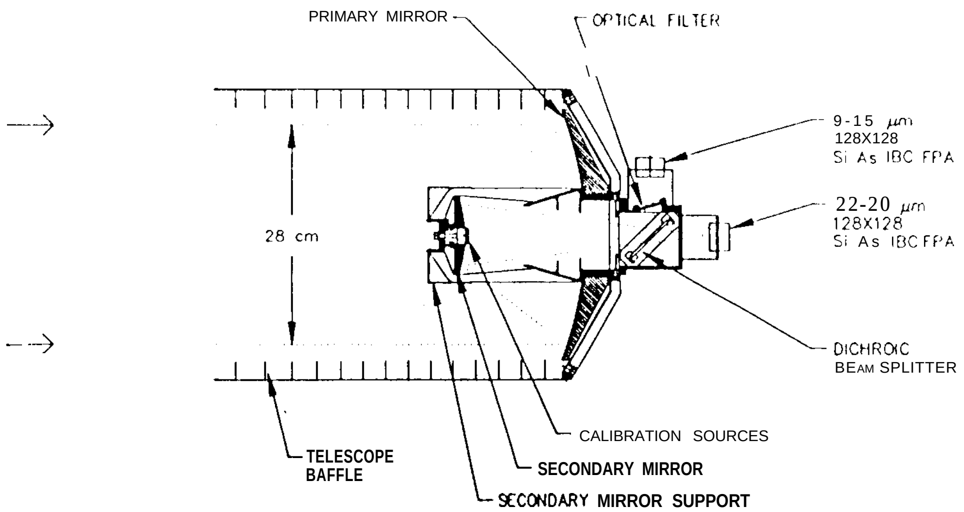


Figure 6. The WIRE optical concept.

testing, except for a separate cryostat test at appropriate facilities. The H_2 cryostat will pose no launch site safety or servicing problems, since the fully loaded system will be sub-cooled and sealed during all launch site operations.

5.1 Cryostat

The cryostat, to be built by Lockheed Palo Alto Re-search Laboratory, is a straightforward adaptation of previous 1,ockheed systems and the recently space-qualified solid H_2 SPIRIT 111 to be flown in 1993. A solid Hz cryostat was selected for the WIRE mission because of its low mass, simplicity, lifetime and low cost. Alternatives to solid H_2, including superfluid helium(SFHe), were carefully considered. The mass of a 4-month lifetime SFHe system would be double that of the dual solid H_2 cryostat. Because the latent heat of H_2 is almost 100 times that of He, a solid 112 system is far smaller and less sensitive to small increases in heat load than SFHe system of comparable lifetime.

The use of H_2 has been thoroughly examined and poses no serious safety risk for several reasons: (1) Only small quantities of H_2 are involved (less than 3 kg total); (2) Instrument testing and calibration will use onl y normal boiling point helium as the cryogen; (3) The 11_2 system test takes place in available Lockheed facilities specially designed for this purpose; and (4) After the cryostat is filled with H_2 and pumped down at the launch site, no venting is necessary until after the instrument is on orbit.

The WIRE cryostat shown in Figure 7 incorporates two solid 11_2 toroidal tanks inside an aluminum vacuum enclosure. The 3.8 liter primary H_2 tank cools the two focal planes to 7.2 K, well below the requirement. The larger, 36 liter secondary tank provides the structural support for the telescope and primary tank as well as cooling the optics to 13 K and providing thermal protection for the primary tank. A laboratory demonstration of key elements of this design has been successfully performed at Lockheed. A vapor-cooled shield using H_2 vapor sublimed from the secondary tank provides thermal protection for the secondary tank and optics module. The vapor-cooled shield and secondary tank are thermally isolated from the vacuum shell by folded, concentric glass/epoxy support tubes and multi layer insulation consisting of double- aluminized mylar with silk net spacer. Graphite/epoxy support tubes and low-emittance surfaces provide thermal isolation of the primary tank and focal planes from the secondary tank and optics. Liquid helium coolant lines are used to subcool both tanks and provide ground servicing of the cryostat during testing and prior to launch. All electrical connections, fill, vent, and cooling plumbing penetrate the vacuum shell at the girth ring, which also provides the structural interface between the WIRE instrument and the spacecraft. The entire system represents no new development but rather the application of known and demonstrated techniques in cryostat engineering.

The optical assembly and cryostat will be built and tested separately prior to integration. The optics module simply "plugs" into the cryostat through the front end with the optical bench being bolted directly to the secondary J 1_2 tank. The focal planes are thermally linked to the primary H_2 tank through a flexible shrink-fit connection, identical to that used successful] y in SPIRIT III. Focal plane cables and connections in the cryostat and in the optics module are mated using tapered guides. A small orthoscope will be used to observe both the thermal shrink fit and electrical connections as mating occurs. This "plug-in" cryostat technology provides convenient modular testing and integration.

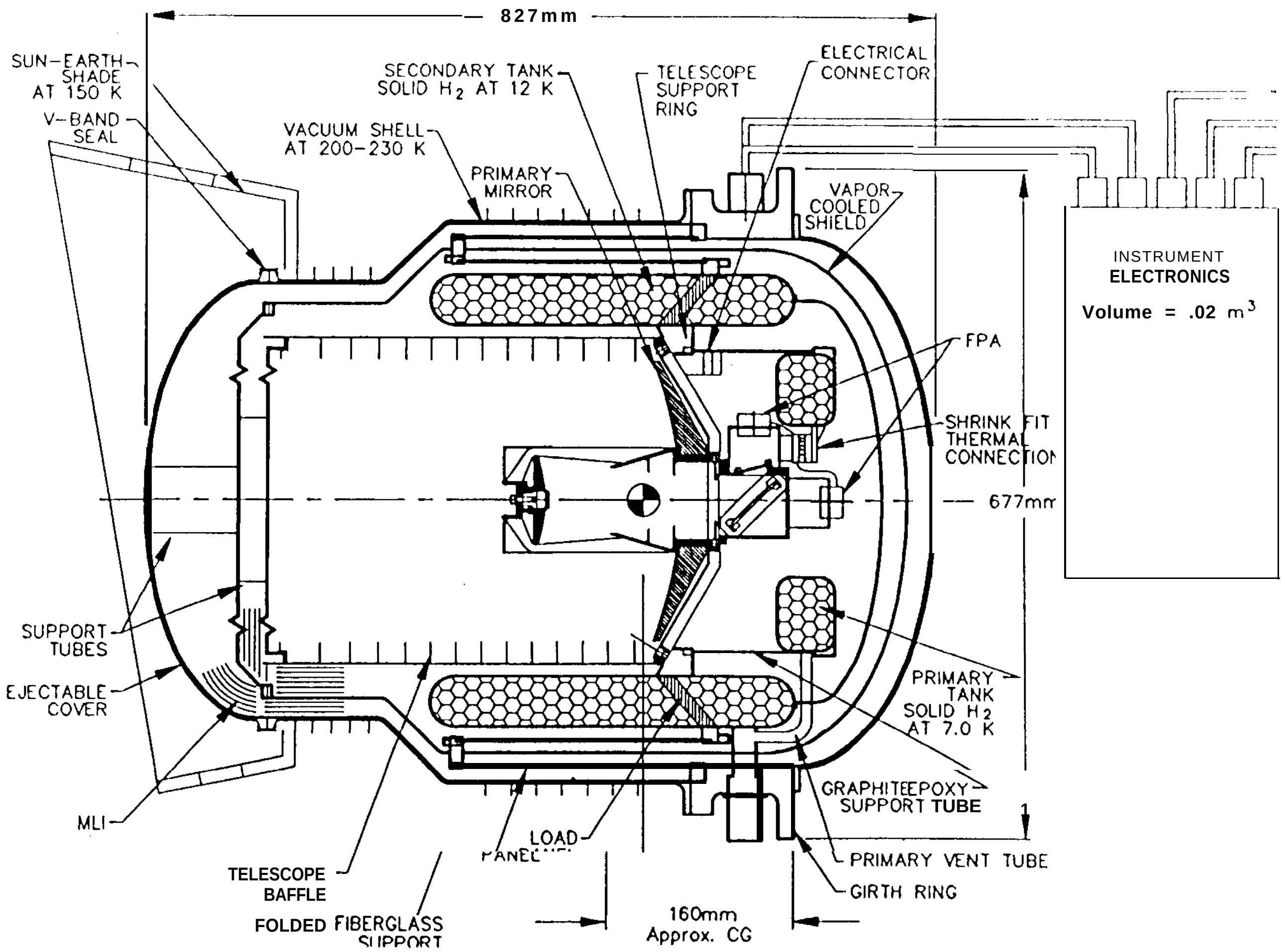


Figure 7. Cross-section sketch of the WIRE instrument.

An ejectable aperture cover seals the cryostat after the telescope is installed. The cover includes two radiation shields, one conductively linked to the vapor-cooled shield and the other to the top of the telescope baffle, to provide thermal protection while on the ground. After WIRE reaches orbit and has sufficiently outgassed, pyrotechnic devices release the V-band retaining the aperture cover and springs eject the cover away from the instrument.

The aperture shade, shown in Figure 7, is radiatively cooled to 150 K and provides both thermal and straylight protection. The shade is designed with Sun and Earth avoidance angles of 80° allowing WIRE to easily meet sky coverage requirements.

Multilayer insulation will also be used on the exterior of the vacuum shell to thermally isolate it from the spacecraft and solar panel. A high emissivity coating on all unblanketed external surfaces will provide an average vacuum shell temperature in the 200 - 230 K range. Similar techniques on CLAES resulted in measured on-orbit vacuum shell temperatures averaging near 200 K.

5.2 Optics

The WIRE optical system is simple (see Figure 4). It consists of a standard Ritchey-Chretien Cassegrain telescope, one dichroic beamsplitter, one optical bandpass filter, and baffles. The optical system is diffraction-limited in both spectral bands. The parameters of the optical system are tabulated in Table 1. Fabrication and alignment tolerances are liberal because there are only two powered optical elements and because the wavelengths of operation are well into the infrared. Thus, the structure can be lightweight without increasing risk or rest.

The telescope mirrors are diamond-turned aluminum with an aluminum coating protected by a silicon monoxide overcoat. Despite some "creep," aluminum is adequate to meet the diffraction limit at $25\mu m$. The primary mirror is made lighter by diamond turning the back surface to a conical shape. The mirrors and optical bench are all made from the same type of aluminum so that thermal contraction just scales the telescope. Thus, the telescope can

TABLE 1. Optical System Parameters

Focal Length	980 mm	
Aperture	280 mm, f/3.5	
Central obscuration	0.4 linear (0.16 area)	
Angular width of pixel	76.5 μrad (15.8 arcsec)	
Angular width of detector array	9.79 μrad (33.7 arcminutes)	
Weight	9.1 kg	
Size	Maximum diameter : 330 mm	Length: 581 mm
Spectral passband	hand 1: 9 to 15 μm	Band 2: 22 to 28 μm
In-band transmittance	Band 1: 0.65	Band 2: 0.60
Out-of-band-transmittance	Band 1: $<10^{-3}$	Band 2: $<10^{-3}$

be aligned at ambient temperatures but used at cryogenic temperatures. This warm alignment is accomplished by manual tip, tilt, decenter and focus adjustments at the secondary mirror. The cooled assembly remains in alignment and focus because internal stresses in the mirrors and optical bench have been relieved by heat treating methods.

The optical bench passes through the center of the primary mirror and provides the central baffling required by the Cassegrain configuration. This central optical bench concept, sometimes called the Meinel configuration, reduces mass and is a flight-proven design, This concept has been exploited in the WIRE instrument by bolting the assembly containing the beamsplitter, filter and FPAs to this central bench so that the entire optical system is an independent module which "plugs" into the cryostat. Thus, the optical system and FPAs can be tested independently of the cryostat.

The dichroic beamsplitter reflects wavelengths shorter than 22 μm and transmits wavelengths from 22 to 28 μm. The optical bandpass filter reduces the passband of the light reflected from the beamsplitter to 9 to 15 μm. The filter is slightly tilted to minimize ghost images.

5.3 Detectors

The detectors are the heart of the WIRE instrument. They make revolutionary gains in sensitivity and sky coverage possible with such a simple instrument. Current device technology provided by Rockwell International meets or exceeds all WIRE focal plane array functional requirements. The functional requirements for the WIRE focal plane arrays are given in Figure 1; additional requirements are shown in Table 2.

TABLE 2. Additional WIRE Focal Plane Functional Requirements*

Parameter	WIRE Requirement
Responsivity Uniformity	<470
Responsive Pixels, Total Array	> 95%
Non-Linearity over Dynamic Range	< 10%
Maximum Integration Time	64 sec
Radiometric Stability peak-to-peak drift (60 sec at 8 K)	< 1%
Allowable FPA Power Dissipation (each)	< 2.5 mW

* All requirements are met or exceeded in WIRE baseline design. Primary FPA requirements appear in Figure 1.

The two focal plane arrays for WIRE will use arsenic doped silicon (Si:As) detectors operating in the IBC mode, These detectors are responsive from below 8pm to 28pm. IBC detectors were developed in 1979 by Rockwell to improve the performance of extrinsic silicon IR detectors and to reduce sensitivity to ionizing radiation. Matching cryogenic Switched MOSFET Multiplexers, (SWIFETs) were specifically developed to interface to these enhanced performance detectors. These multiplexer are mated to the detectors using standard iridium bumpbonding techniques to form hybrid Focal Plane Arrays (FPAs). Hybridization of the focal planes allows both the detector array and the multiplexer array to be optimized independently. Synergism between detector and multiplexer technology has lead to many performance enhancements and rapid maturation of this technology, The resulting hybrid FPAs are well-suited for use in space-based astronomy,

6.0 MISSION DESCRIPTION

6.1 Mission Design

Orbit. The baseline orbit for the WIRE mission is a 400 km altitude sun-synchronous circular orbit (inclination of 970), which is achievable using the standard Pegasus configuration and includes a 15% mass contingency on the instrument and spacecraft masses. This orbit was chosen because the spacecraft power subsystem is sized assuming that WIRE flys in a dawn-dusk type orbit, which remains cclipsc-free for substantial periods of time (over 8 months in the current orbit). This allows WIRE to have smaller fixed solar arrays and a smaller battery, saving about 20 kg and simplifies the operation of the mission. The IRAS and COBE missions also used sun-synchronous orbits, In 1997 (which is close to a minimum in solar activity) wc expect to see an altitude drop of about 20 km over 4 months from the 400 km altitude duc to atmospheric drag. The time of year in which the launch may occur is driven by the need to have an eclipse-free mission; therefore, the mission should be roughly centered on either the winter or summer solstice.

Observing Efficiency. Observing efficiency is defined to be the total available detector exposure time divided by the mission lifetime. The observing efficiency estimate for WIRE is 73%. Observing efficiency dots not address how the exposure time is used, only how much is available. Another type of efficiency called primary target efficiency. This is the expected amount of time available over the mission life that may be spent examining the primary science target fields, taking into account all expected data outages and losses, target availability, on-orbit checkout, anomalies, calibration activities and radiation effects . The primary target efficiency is 37% well above that required to meet the science requirements.

Pointing. The pointing requirements for the WIRE mission are derived from the basic science requirements on image quality and the necessary capability to be able to co-add frames on the ground. Pointing accuracy has to be 2 arcmin and pointing stability 19 arcsec over a single exposure (both numbers are 2σ, radial). The WIRE baseline assumes a pointing stability of 12 arcsec, based on information from the SMEX office that this level of performance is readily achievable.

Avoidance Constraints. The WIRE design contains an aperture shade (see Section 5.1, and Figure 7) which allows WIRE to tilt towards the Sun by 10° (i.e. 80° Sun avoidance from the spacecraft-Sun line). The Earth avoidance angle is 150° from Earth center, allowing WIRE to look in a cone 30° about the spacecraft zenith. The Sun and Earth constraints must be maintained at all times. An additional constraint to remain more than 20° from the Moon limb must only be maintained only during observations.

Radiation Environment. The radiation environment has been examined and does not present a problem for the WIRE mission. As an example, a shielding of 0.50 g/cm^2 (equivalent to about 2mm of Aluminum) would give a totat mission dosage of about 400 rads, an insignificant level for these detectors. We conservatively estimated the detector hit rate by assuming the IRAS South Atlantic Anomaly critical flux contour of 10 $protons/cm^2/sec$ above 50 MeV. At this worst-ewe rate, which comprises only 5% of the mission, about 10% of the array would be hit during a single exposure. Since the WIRE orbit is lower that I RAS (400 km for WIRE vs. 900 km for IRAS), the actual WIRE rate will be considerably lowered.

6.2 Mission Operations

Typical Science Operations Scenario. WIRE flight operations require only one observation mode. The spacecraft is commanded to point to a particular position (RA and DEC). Once there the observation begins. Observations consist of a series of short exposures lasting from 32–64 seconds. Small, pre-determined pointing offsets may be applied after each individual exposure. This continues for the maximum time that the target is available for viewing, that is, until the Earth avoidance constraint is about to be violated. Targets will be observed on consecutive orbits until the required 11,000 seconds exposure time is accumulated per field.

On-Or-bit Checkout. On-orbit checkout will last nominally for one week, during which time the spacecraft, telescope, and instrument systems will be checked prior to start of the primary mission phase. Checkout will include: testing spacecraft slewing and capability to maintain avoidance constraints, ejecting the aperture cover, observing internal and external calibration sources to characterize the detector performance, characterizing the stability of the internal stimulators, and flat field verification.

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REFERENCES

1.) Soifer, B. T., and Neugebauer, G. 1991, A. J., 101, 354.

2.) Rowan-Robinson, *et* al. 1991, Nature, bf 351, 719.

3.) Soifer, B. T., *et* al. 1987, Ap. J., 320, 238.

4.) Fisher, K. B., Strauss, M. A., Davis, M., Yahil, A., and Huchra, J. P. 1992, Ap. J., 389, 188.

5.) Hacking, P., and Houck, J. Ft. 1987, Ap. J. (Supplements), **63** , 311.

6.) Hacking, P., Condon, J. J., and Houck, J.R. 1987, Ap. J. (Letters) , 316, 1,15.

7.) Lonsdale, C. J., and Hacking, P. B. 1989, Ap. J. 339, 712.

8.) Lonsdale, C. J., Hacking, P. B., Conrow, T. P., and Rowan-Robinson, M. 1990, Ap. J., 358, 60.

9.) Saunders, W., *et al.* 1990, M. N. R. A. S., 24, 318.

10.) Hacking, P. B., Houck, J. R., Soifer, B. T., in progress.

11.) Condon, J.J. 1984, Ap. J., 287, 461.

12.) Sanders, D. B., Phinney, E. S., Soifer, B. T., and Matthews, K. 1989, Ap. J., 347, 29.

13.) Beichman, C. A., *et al.* 1986, Ap. J. (Letters), 308, 1,1.

14.) Sanders, D. B., *et al.* 1988, Ap.J., 325, 74.

15.) Helou, G. 1986, Ap. J. (Letters), 311, 1,33.

16.) Ames, H.O. and Burt, D. A., 1992, "Development of the SPIRIT 111 sensor," SPIE Technical Conference 1765, San Diego.